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13. ABSTRACT (Maximum 200 words)

The following research problems were investigated in this program of theoretical solar plasma physics. 1. Three Dimensional Reconnection: A model with axially bounded magnetic flux tubes has been suggested as a source of coronal heating. Numerical simulations have supported this theory; 2. Fast Reconnection: A reconnection rate for the driven reconnection of solar coronal loops and other axially bounded magnetic fields has been obtained: 3. Approximate Equilibrium States: Equilibrium states appropriate for coronal flux tubes and for the magnetic tail of the magnetosphere have been constructed analyticaly and numerically; 4. Boundary Conditions: A full solution for plane symmetry has been obtained for standing plasma waves with a discontinuous anchoring conductivity; 5. Alfven Waves: It has been shown that highly energetic ions can resonantly destabilize Alfven waves but the effect of Kelven Helmholtz turbulence prevents further Alfven wave growth, limiting them to a small fraction of the beam energy; 6. Ballooning Modes: The general ballooning equations have been developed. Very simple configurations have been found to be always unstable.

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PROGRESS REPORT
H. STRAUSS & E. HAMEIRI
AFOSR-91-0044

Courant Institute, New York University

1. 3D Reconnection (H. Strauss)

Reconnection in three dimensions has been investigated in axially bounded magnetic flux tubes. This models a process conjectured to heat the solar corona. Flows in the photosphere stir the coronal magnetic field, causing the formation of intense current sheets, in which magnetic energy is dissipated. This picture, due originally to Parker, has been controversial. Our work lends support to the theory.

A condition for reconnection is a velocity stagnation line. A current sheet forms at the stagnation line, which must also coincide with a magnetic field line to avoid large unbalanced forces. The presence of a current sheet implies that magnetic field lines passing near the sheet will be widely separated from the moving plasma; so that plasma elements originally connected by field lines are latera no longer connected. The distance between the original field lines and fluid elements becomes of order of the system size as field lines are pulled near the current sheet. Numerical simulations verify the analysis. The simulations concerned a form of driven reconnection appropriate to space and astrophysics, and showed that fast reconnection could occur with peak current density scaling as the plasma conductivity.

Strauss, H. R., Three Dimensional Reconnection in an Axially Bounded Magnetic Field, *Ap. J., 381*, 508, 1991

2. 3D Fast Reconnection (H. Strauss)

Fast reconnection is essential to explain magnetic energy release in solar flares,

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as well as providing the rapid magnetic energy dissipation required in coronal heating theories. We have obtained a reconnection rate driven reconnection of solar coronal loops and other axially bounded magnetic fields. The reconnection time in 3D driven reconnection has been found to scale as $t \sim \log S$, where S is the magnetic Reynolds number, or Lundquist, number, the ratio of Alfvén wave transit time along the magnetic field to the resistive diffusion time. This scaling is the famous Petschek reconnection scaling. This is the first verification of this fast reconnection time scale in three dimensions. The details of the reconnection process differ from Petschek's model. A simple 1D analytical model is given which reproduces the basic features of the 3D simulations. The model works because the reconnection takes place in an elongated current sheet, which is narrow only in the inflow direction of the stagnation flow.

Strauss, H. R., Three Dimensional Fast Reconnection, submitted to *Ap. J.*, 1992.

3. Approximate Equilibrium States (E. Hameiri, R. Young)

Coronal flux tubes have a typical aspect ratio of about 1:10. Thus, it is appropriate to describe their equilibrium state in the long-thin approximation. A similar situation holds for the magnetic tail of the magnetosphere which is stretched due to the action of the solar wind. We have constructed, analytically and numerically, such equilibrium states. We allow for mass flow along field lines, as well as motion of a plasmoid down the field line. The plasmoid may result from magnetic reconnection during solar flare activity, or during a substorm in the magnetotail case. Our plasmoid is a blob of plasma of finite extent, moving against a background at rest. To our knowledge, this is the first such solution in the literature. Recently, Birn [*Phys. Fluids B* **3**, p. 479, 1991] has produced a plasmoid solution. Unlike our result, however, his plas-

moid is infinitely long and the background plasma needs to be in some state of flow as well. In the future we will consider the stability of such magnetic structures.

R. Young and E. Hameiri, Approximate magnetotail equilibria with parallel flow, submitted to *J. Geophys. Res.*, 1991.

4. **Boundary Conditions** (E. Hameiri, M. Kivelson)

The solar corona is bounded by the much colder photosphere and chromosphere, where the plasma can no longer be taken to have an infinite conductivity. Moreover, in a sunspot, the inner region (umbra) is colder than the outer region (penumbra), giving rise to a discontinuity in the electrical conductivity which coronal field lines are anchored to. A similar situation occurs in the magnetosphere due to the finite ionospheric conductivity and the dayside-nightside discontinuity. We have further developed our earlier magnetospheric work and now give a full solution for standing plasma waves with a discontinuous anchoring conductivity. The next step in this work will be to deal with cylindrically symmetric, sunspot-like, solutions rather than the plane symmetry used up to now.

The results have been submitted to *J. Geophys. Res.*

5. **Alfvén waves**

Solar flares produce highly energetic ions, whose speed can exceed the Alfvén speed, and which can resonantly destabilize Alfvén waves. The waves grow and at a critical amplitude, the velocity gradient in the waves is large enough to excite secondary Kelvin Helmholtz instabilities. The effect of the Kelvin Helmholtz turbulence prevents further Alfvén wave growth. The critical amplitude for secondary Kelvin Helmoltz instability is rather low, so the Alfvén waves are limited to a small fraction of the beam energy.

Meytlis. V. P. and Strauss, H. R.. Excitation of Alfvén Waves and Local Turbulence by Energetic Ion Beams. *J. Geophys. Res.*, in press. 1992.

6. **Ballooning Modes in Classical Fluids** (E. Hameiri. A. Lifschitz)

The rotation of the sun determines in some indirect way the 11-year solar flare cycle. This steady state motion of the sun must be subject to some constraints, such as stability against various modes. We have undertook to investigate the requirements for stability against ballooning modes. In the solar interior the magnetic field is usually weak and may be ignored. Interestingly, ballooning modes which were discovered for magnetic field-dominated plasmas, still exist for unmagnetized fluids. They are localized to streamlines and are driven by pressure gradients. We have developed the general ballooning equations (which only involve ordinary differential equations along streamlines) and, so far, have looked at the stability of very simple configurations, such as the neighborhood of stagnation points. Remarkably, we find that such configurations are always unstable. More complicated flows will be explored in the future.

A. Lifschitz and E. Hameiri, Local stability conditions in fluid dynamics, in press, *Phys. Fluids A*, 1992.

NEAR-FUTURE WORK

1. **3D MHD Simulations**

A general 3D finite difference MHD code has been written by W. Lawson. The code is in the testing stage, with most bugs eliminated. The main application is intended to be reconnection in solar and space plasmas, such as modelling solar flares. The code will also be applied to the related topic of compressionally driven reconnection. Preliminary computations with the code include the

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nonlinear kink instability. Another test computation shows an arcade being twisted up to form a loop, overlying a filament or prominence structure. Simulations have also been done of a 3D reconnection flare model, in which the reconnection of the magnetic field and formation of a plasmoid is driven by inflow toward the neutral line of an arcade. The arcade has to part of a larger flux system with opposite polarity for the eruption to occur.

Now that the code is becoming operational, we expect to make rapid progress in numerical simulations of solar flare models.

2. Eruption of solar prominences:

A prominence is held down by a surrounding magnetic arcade. Motions in the photosphere cause changes in the arcade configuration. We can show that some particular motions will cause the confined prominence to balloon upwards and eventually to erupt upwards, as seen in observations. We hope to demonstrate this phenomenon by an analytical solution.

3. Resistivity Gradient Driven Instabilities in Sunspots

Sunspots contain low temperature weakly ionized plasma, with a temperature of about $3300°K$. The resistivity is a very steep function of temperature. Magnetic fields penetrating the sunspot carry a current, if the overlying coronal field has stored energy. We examined resistivity gradient driven modes, which resemble rippling modes, except that the wavevector along the magnetic field, $k_{\parallel}$, is not assumed small. Turbulent thermal diffusion produced by the modes is calculated, assuming the turbulence stabilizes the longest wavelength mode. These modes could be an important cause of turbulence at the edge of sunspots, and might explain the decay rate of the spots.

Meytlis, V. P. and Strauss, H. R., Resistivity Gradient Driven Instabilities in Sunspots, in preparation, 1991

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4. **Coronal boundary conditions:** Extension of the magnetospheric work of Hameiri and Kivelson to the solar case. An added complication here is the great radial expansion of magnetic flux tubes from their photospheric size to their coronal size, due to the increase in temperature and pressure along the field line and the accompanying decrease in magnetic field strength.

Meetings attended

AAS Solar Physics (Huntsville, April, 1991).

Gordon Conference on Solar Plasmas and MHD Processes (August 5 - 9, 1991).

American Physical Society, Div. of Plasma Physics (Tampa, November, 1991).